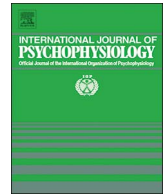




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Evidence for a neural signature of musical preference during silence

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ABSTRACT

One of the most basic and person-specific affective responses to music is liking. The present investigation sought to determine whether liking was preserved during spontaneous auditory imagery. To this purpose, we inserted two-second silent intervals into liked and disliked songs, a method known to automatically recreate a mental image of these songs. Neural correlates of musical preference were measured by high-density electroencephalography in twenty subjects who had to listen to a set of five pre-selected unknown songs the same number of times for two weeks. Time frequency analysis of the two most liked and the two most disliked songs confirmed the presence of neural responses related to liking. At the beginning of silent intervals (400–900 ms and 1000–1300 ms), significant differences in theta activity were originating from the inferior frontal and superior temporal gyrus. These two brain structures are known to work together to process various aspects of music and are also activated when measuring liking while listening to music. At the end of silent intervals (1400–1900 ms), significant alpha activity differences originating from the insula were observed, whose exact role remains to be explored. Although exposure was controlled for liked and disliked songs, liked songs were rated as more familiar, underlying the strong relationship that exists between liking, exposure, and familiarity.

1. Introduction

Sometimes it's the space between the notes that makes all the difference in music. Silence in music conveys information of major importance that was efficiently used by composers like Mozart who mentioned that “music is not in the notes, but in the silence between”. Some authors have suggested that high-level musical information, such as familiarity, is also present during silence: “When you listen to Mozart, the silence that follows is still Mozart” (Guitry, 1947).

In the early 2000s, neuroimaging studies confirmed that familiarity was processed during silences, even when these silences were artificially inserted into music (Kraemer et al., 2005; Gabriel et al., 2016). When inserted in familiar music, these silences automatically convey the sensation of hearing a song internally without any audible sound, in continuation of what had just been heard before. This is referred to as spontaneous auditory imagery. As a consequence of spontaneous imagery, a neural activity within regions of secondary auditory cortex, of

the dorsolateral prefrontal cortex and of the supplementary motor area is generated (Kraemer et al., 2005). In electroencephalography (EEG), the response to familiar music is reflected by an increase in theta power during the whole silence period (Gabriel et al., 2016). Interestingly, the neural familiarity mechanisms occurring during auditory imagery are similar between familiar songs and songs passively learned for two weeks, showing the efficiency of passive learning processes in encoding musical information (Gabriel et al., 2016).

The present investigation sought to determine whether aesthetic musical judgement is also present during silence in music. When we like listening to Mozart, do we still like Mozart during the silences in its music? Music is a complex stimulus, and its affective dimension is an integral part of the artistic and aesthetic experience, and the hedonic appreciation of music, referred to as music liking, involves activation of areas responsible for the feeling of pleasure (Blood and Zatorre, 2001). The hypothesis of a preservation of liking during auditory imagery is based on the important influence of familiarity on liking: becoming

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more familiar with a particular piece of music increases the subject's liking ratings for it (Pereira et al., 2011). Familiarity and liking being two high level information processes often co-occurring when listening to music (Stalinski and Schellenberg, 2013), they may as well co-occur during musical imagery. A second argument supporting that liking may be maintained is based on the fact that emotions are preserved during auditory imagery (Lucas et al., 2010).

The neural structures responsible for the mechanisms of liking have only been explored while listening to music. Neuroimaging methods have linked the activation of several cerebral areas to pleasure states when listening to music: the dorsal and ventral striatum, right caudate nucleus, ventral putamen and nucleus accumbens in relation to dopamine release in the reward system (Salimpoor et al., 2011). A functional architecture including anterior cingulate cortex, amygdala, insula, orbitofrontal cortex and nucleus accumbens as areas providing evaluative responses such as the reward value of the stimulus has also been suggested (Salimpoor et al., 2015; Clark et al., 2014). Other structures such as the inferior frontal gyrus (IFG) and the superior temporal gyrus (STG) have been found to be specifically activated during liking/disliking processes (Pereira et al., 2011; Koelsch et al., 2006).

A few recent studies have described the use of EEG in listening situations to investigate the temporal dynamics of liking. Partially discordant results were found in terms of brain rhythms among these studies. When comparing consonant to dissonant music, a positive correlation between the synchronization in the mid-frontal theta band and the liking score emerged, especially towards the end of the excerpts (Sammler et al., 2007). Two other studies (Hadjidimitriou and Hadjileontiadis, 2012, 2013) reported that beta and gamma bands were the best features to separate pleasant from unpleasant music, followed by alpha and theta bands. In a recent study a biomarker of music liking has been defined, relying on brain activations recorded over the left prefrontal cortex and focusing on the functional coupling between high-beta and low-gamma oscillations (Adamos et al., 2016). The discrepancies observed in all EEG studies may be attributed to the interference of the physical processing of sounds that impair the detection of the electrophysiological activity related to liking.

Should liking processes be present during spontaneous auditory imagery, we aimed to investigate whether the spatiotemporal dynamics would be similar to those observed in listening situation. Such a preservation of high-level information processes has already been observed during deliberate auditory imagery. Several studies report similar spatial and temporal processes during the musical perception and the voluntary imagery of a song (Halpern and Zatorre, 1999; Linke and Cusack, 2015; Schaefer et al., 2011; Vlek et al., 2011; Zatorre et al., 1996). The mental perception of a familiar piece of music occurs with a high efficiency, and concerns not only the lyrics but also the tempo (Halpern, 1988; Levitin and Cook, 1996), pitch (Halpern, 1989; Janata and Paroo, 2006) and timbre (Halpern et al., 2004). To study these dynamics, we chose to use high-density EEG, whose spatial resolution allows localizing the neural structures involved in liking processes and whose high temporal resolution is adapted to the time-frequency analysis of these events. Our main hypothesis was based on the presence of similar spatiotemporal mechanisms during imagery to those found during music perception. However, no predicted directions were given for time frequency analysis because of the discordant results obtained in previous EEG studies investigating liking during the perception of music. Specific EEG liking responses were thought to spontaneously emerge, especially in the theta band, with neural activations at least partially similar to those observed during listening situations.

2. Methods

The present study is a complementary analysis of the data from the study of (Gabriel et al., 2016) whose primary objective was to explore the onset of the memory dynamics that lead to the automatic completion of missing lyrics during spontaneous musical imagery.

2.1. Participants

Twenty volunteers (7 male, 13 female, mean age = 32 ± 5 years old) participated in the experiment. All participants were right handed, non-musicians (i.e. had not received any formal musical training or had done so for < 6 years), with no neurologic or psychiatric diseases and normal audition. Written consent was obtained from participants prior to taking part in the study, and all received a monetary compensation of 50€. Research methods were approved by the Committee for the Protection of Human Subjects at the Clinical Investigation Center of Besançon (n°14/458).

2.2. Experimental design

Five familiar songs chosen by the participant and five unfamiliar songs selected by the experimenter among original soundtracks recorded by independent or relatively unknown singers were used. Familiar and unfamiliar songs were paired to belong to the same musical genre, sang by a singer of the same sex. All songs were in participants' native language. Loudness levels of all songs were equalized with the Replay Gain algorithm.

The first EEG recording was performed immediately after song selection. All songs were randomly played over headphones and repeated twice. Each Song was 2 min in length and twenty portions were replaced with two-second silent intervals randomly embedded between 10 and 100 s after song onset and with a distance ranging from 2.5 to 3.5 s between gaps. This resulted in 200 trials within familiar songs and within unknown songs. Silence and song presentation were accomplished using the E-Prime software (Psychology Software Tools Inc. Sharpsburg, PA). Participants were instructed to close their eyes and remain still while passively listened to the song. They were requested to rate each song using a visual analog scale (0: unfamiliar; 10: unfamiliar). The knowledge of each song could thus be checked to ensure that subjects did not know any of the unfamiliar songs. After the EEG recording, subjects were required to rate whether they were mentally completing the gaps during the experiment. As expected, all reported mentally completing the gaps except for unknown songs.

Then there was a two-week learning period during which each subject was inquired to listen regularly to the unfamiliar songs, and to note the frequency of song listened to per day in a self-monitoring logbook. The participants listened to each song for an average of 33.89 times (average = 2.39 listening per day). All subjects listened to each of the five unfamiliar songs the same amount of time.

The second EEG recording was scheduled after the two-week learning period. The recording had exactly the same design as for the first EEG, at the exception of the order of the songs that was randomly selected. At the end of the recording, subjects were requested to rate subjective liking/disliking (from 0: disliked to 10: liked a lot), emotions (from 0: very sad to 10: very joyful) and familiarity (from 0: unfamiliar to 10: very familiar) for each song with a visual analog scale.

2.3. Data acquisition and analysis

In this study, we focused on the liking of newly-learned songs, i.e. unknown songs that were learned over the time course of two weeks, because they were controlled to be listened to the same amount of time. Among the five newly-learned songs listened to by participants, the two more preferred and the two least preferred songs were selected. Only the neural responses from the second EEG were considered.

Subjects were seated in a comfortable chair in a dark quiet testing room. EEG signals were recorded using a 256-channel Geodesic Sensor Net (Electrical Geodesics Inc.; EGI, Eugene, OR). Data were continuously recorded with a high-pass filter at 1 Hz, and a sampling rate at 1000 Hz. Epochs of 2500 ms were extracted from the raw data beginning 600 ms pre-silence onset and ending 1900 ms post-silence onset separately for liked and disliked songs. A total of 80 trials were

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